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(54) Title: A NAVIGATION/GUIDANCE SYSTEM FOR A LAND-BASED VEHICLE

(57) Abstract

A navigation/guidance system (10) uses a dead reckoning navigator with periodic GPS fixes to correct the drift of the inertial system. The navigation system (10) primarily uses speed sensed by Doppler radar (30) and attitude and heading sensed by a set of gyros (24). The navigation system (10) uses various processes to compensate for any sensor errors. The system uses attitude data to compensate for GPS leverarm errors. The system can be used on a land-based vehicle (60) to economically and accurately provide navigation data.
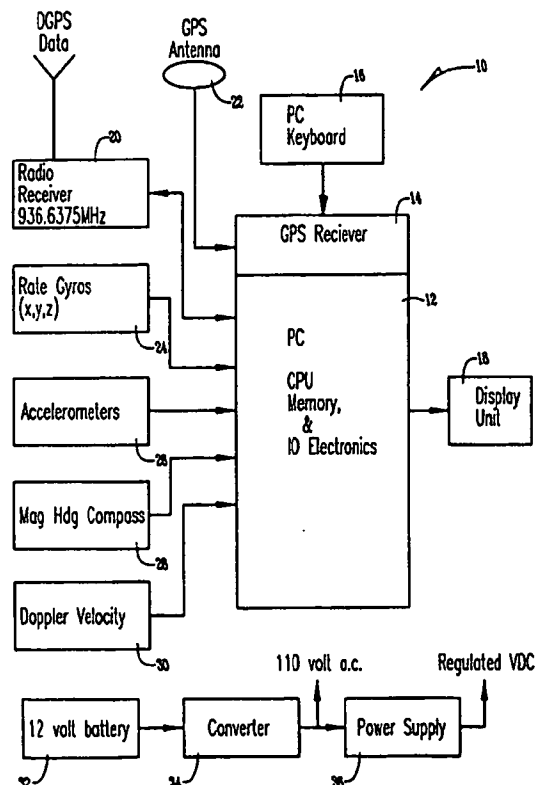
TITLE: A NAVIGATION/GUIDANCE SYSTEM FOR A LAND-BASED
              VEHICLE

BACKGROUND OF THE INVENTION

5   FIELD OF THE INVENTION

The present invention relates to inertial navigation
systems. More particularly, though not exclusively, the
present invention relates to an inertial navigation/guidance
system using a radio navigation receiver to correct the
10 navigation errors.

PROBLEMS IN THE ART

Differential global positioning system (DGPS) based
guidance systems for airborne application of agrochemicals
has met with huge success and it follows that this technology
15 could be used with ground rig applicators if certain
technical problems can be overcome. The primary differences
between air and ground application processes are associated
with the operators view of the land and the operational
dynamic environment.

20   During airborne applications, the pilot generally has a
large part of the area involved to be sprayed in view and the
GPS antenna (mounted on top of the canopy) follows a
relatively straight line when in an application swath. This
provides for the required cross track position stability to
25 obtain a well controlled application process.

With ground rig applicators, such as tractors or
floaters, the operator may have a limited view of the
involved spray area and depending on the size/shape of the
field and of the local ground cover it can be very difficult
30 to determine where the previous swath coverage ends in order
to proceed with the ensuing swath. A GPS antenna mounted on
top of the ground vehicle (where it would be exposed to the
GPS satellites) will experience large attitude excursions as
the rig swaths the field. This results in GPS derived cross
35 track position excursions relative to the vehicle ground
track which would contaminate any attempt to parallel a
defined field line. It can therefore be seen that there is a

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need for a better navigation/guidance system for use with a ground-based vehicle.

There is a need for a solution to various problems relating to ground rig applicators such as tractors and

5   floaters. These ground rig applicators have several disadvantages. Since the application of agrochemicals is a seasonal process (3-4 months per year), the workers hired to operate the floaters are seasonal workers. As a result, the seasonal workers are often inexperienced or unreliable in the

10   operation of the floaters. This increases the probability that the operator will skip areas of the field or apply double coverage to overlapping areas. These problems cost the seller of the chemicals and the farmer thousands of dollars. A typical floater will cost $100,000 and will apply

15   $500,000 - $1 million dollars worth of chemicals per year. It can therefore be seen that efficient operating of a floater is very important. Typical prior art floaters are guided through a field by following a trail of foam markers which are marked on the field on the previous swath. As a

20   result, there is a lot of room for human error and the floaters cannot be operated at night. A need can therefore be seen which would allow the floaters to operate accurately day or night throughout the season. Such a solution would allow a chemical applier to operate half as many machines.

25   An accurate, real-time inexpensive navigation/guidance system would remedy these problems.

Various prior art navigation systems for ground-based vehicles have several disadvantages. Systems using Doppler radar will encounter errors with the radar. Similarly, gyros

30   will encounter drift errors which will continue to increase unless the drift error is corrected. Gyros that are inexpensive enough to be feasible to use may have drift rates high enough to make them unusable. For example, a typical inexpensive gyro sensor may have a drift rate uncertainty as

35   high as 3600° per hour which makes the gyro unusable for most applications. As a result, gyros have good short term

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characteristics but bad long term characteristics as the drift error becomes larger as time goes on.

When navigating using dead reckoning you need a very high fidelity heading measurement which has not been achieved adequately using low costs sensors.

Various prior art systems navigating by GPS also have disadvantages. Prior art systems using GPS use GPS as the primary navigator. This intensifies the problems found with GPS. A GPS position calculation has a lag time. As a result, the position solution provided by a GPS receiver tells a user where the vehicle was a moment ago not in real time. Another problem with GPS systems are the errors resulting from the antenna lever arm problem. A GPS antenna typically is a certain distance away from the GPS receiver. Since the GPS antenna is the collection point of the GPS signals received, the position solution will not accurately describe the position of the GPS receiver or some other reference point. If the geometrical distance between the GPS receiver or reference point and the GPS antenna is known, the position of the reference point may be calculated. However, as a ground based vehicle travels over uneven terrain such as terraces, slopes, ruts, bumps, etc., the actual position of the GPS antenna cannot be determined resulting in erratic GPS position solutions.

Most prior art attempts to use a GPS navigation system attempted to deal with problems by correcting GPS drift and lag time. However no prior art system navigating by GPS has achieved the high accuracy and real time solutions required for applications requiring a high level of accuracy. The prior art attempts have not provided an adequate solution because GPS does not provide a continuous navigation solution. A GPS system will update its position periodically, not in real time, and a lag time is still involved. Another problem with a GPS system is the possibility of a signal dropout of the satellite signals. The accuracy of a GPS system is also limited due to the errors caused by the ionosphere. Another problem with GPS

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systems is that altitude data provided by a GPS receiver is
not precise.

Another problem with GPS systems is that a GPS system
cannot accurately supply guidance data for a curved path.
5   This problem relates to the lag time involved with GPS. A
GPS system can only do linear interpolation of GPS position
solutions which is inadequate for navigating a curved path.
A GPS system also will not provide high quality heading
information. Finally, the altitude calculated by a GPS
10   receiver is inaccurate and unusable for certain applications.

FEATURES OF THE INVENTION

A general feature of the present invention is the
provision of an inertial navigation/guidance system.

A further feature of the present invention is the
15   provision of an inertial navigation/guidance system for use
on a land-based vehicle.

A further feature of the present invention is the
provision of an inertial navigation/guidance system that
senses the attitude of the vehicle.

20   A further feature of the present invention is the
provision of an inertial navigation/guidance system which
uses a radio navigation receiver to correct the drift errors
of the inertial system.

A further feature of the present invention is the
25   provision of an inertial navigation/guidance system which
uses inexpensive sensors to achieve a highly accurate result.

A further feature of the present invention is the
provision of an inertial attitude determination system which
is stand alone.

30   A further feature of the present invention is the
provision of an inertial navigation/guidance system which
uses gyro information to compute the attitude and heading of
the vehicle and a position change sensor to sense the speed
of the vehicle.

35   A further feature of the present invention is the
provision of an inertial navigation/guidance system which

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uses accelerometers to measure the pitch and roll of the vehicle to refine the sensed attitude of the vehicle.

A further feature of the present invention is the provision of an inertial navigation/guidance system which
5   includes software to control the functions of the system.

A further feature of the present invention is the provision of an inertial navigation/guidance system which uses the sensed attitude of the vehicle to determine the position of the radio navigation antenna in order to correct
10   the lever-arm error.

A further feature of the present invention is the provision of a system for use on a boat or ship.

A further feature of the present invention is the provision of a system which is part of a surveying system.
15   These as well as other features of the present invention will become apparent from the following specification and claims.

SUMMARY OF THE INVENTION

The navigation and guidance system of the present
20   invention provides accurate navigation data in real time using a dead reckoning navigator with periodic radio navigation fixes to correct for the drift of the inertial system. The system senses the speed, heading and attitude of the vehicle to determine a position of the vehicle. An
25   external position reference provided by the radio navigation system is used to correct any error in the determined position.

The system is capable of correcting for the radio navigation antenna lever arm errors by using the attitude of
30   the vehicle. The system may optionally be used on a ground or water based vehicle to provide navigation data and guidance commands to an automatic steering system. The system of the present invention may also be used on a agricultural vehicle to guide the vehicle through a field in
35   a number of ways.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a block diagram of the primary hardware elements of the navigation/guidance system of the present invention.

5   Figure 2 shows a functional block diagram of the attitude/heading portion of the present invention.

Figure 3 shows a functional block diagram of the position correction function of the present invention.

Figure 4 shows a functional block diagram of the dead

10   reckoning navigation function of the present invention.

Figure 5 shows a functional block diagram of the guidance function of the present invention.

Figure 6 shows a tractor using the system of the present invention.

15   Figure 7 is an aerial view of a field being worked by the tractor shown in Figure 6.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention will be described as it applies to its preferred embodiment. It is not intended that the

20   present invention be limited to the described embodiment. It is intended that the invention cover all alternatives, modifications, and equivalences which may be included within the spirit and scope of the invention. While the present invention is described as being used on a land based vehicle,

25   it is intended that the invention cover other applications. Also, the term land-based vehicle is meant to include vehicles on the ground or in the water, "land-based" is meant only to distinguish from airborne applications.

The navigation/guidance system of the present invention

30   is a dead reckoning navigator which uses periodic GPS fixes to correct the drift of the inertial system. The system uses GPS antenna attitude compensation to improve the accuracy of the GPS fixes. The system primarily uses speed sensed by Doppler radar and attitude and heading sensed by a set of

35   gyros. As discussed above, systems using a Doppler sensor and gyros have the problem of errors in the sensors. In addition, in order to use inexpensive sensors, very large

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errors are encountered. The system uses various processes to
compensate for the errors. The heading sensed by the gyros
is aided by a magnetic heading compass and a GPS receiver.
The speed sensed by the Doppler radar is also aided by the
5   GPS receiver. The system also uses accelerometers to improve
the accuracy of the system. A set of horizontal
accelerometers measure the roll and pitch of the vehicle.
This is used to provide the attitude integration algorithm
(discussed below) with the vehicle horizontal rotations to
10   more accurately calculate the attitude and heading.
         Figure 1 shows the primary hardware elements of the
inertial navigation/guidance system 10 of the present
invention. The system 10 is comprised of a personal computer
(PC) 12 which includes a CPU, memory and input/output
15   electronics. Although the embodiment shown in the drawings
shows a personal computer, the invention could use a
processor circuit that includes a CPU, memory, and
input/output electronics on a single processor card. A GPS
receiver 14 plugs directly into an open PC expansion slot.
20   Any GPS receiver suitable for use with the present invention
may be used, however the preferred GPS receiver is the
NovAtel GPS receiver card #951R. Alternatively, the system
10 could simply have a connector that would receive GPS data
from any existing GPS receiver. Any other type of radio
25   navigation system or combination of systems could be
substituted for the GPS system such as LORAN, GLONASS, etc.
A keyboard or keypad 16 is connected to the PC 12 and is used
as a user interface to input data or control the system 10.
A display unit 18 is also connected to the PC 12. The
30   display unit 18 is used to display various information to a
user. The display unit 18 could take on many forms, but is
preferably comprised of a CRT display. The display unit
could even be comprised of a display screen that shows the
operator a graphic of a field or portion of the field and
35   could indicate where the vehicle has been and where it is
going. All sensor input data to the PC 12 will be digital
serial. If any of the selected sensors provide only analog

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outputs, A/D converters will be used where required to obtain the appropriate input data formats. Also shown in Figure 1 is a block diagram of the power supply circuit used by the present invention. The power supply circuit includes a 12
5   volt battery 32, a voltage converter 34 and a power supply 36. The power supply circuit provides the system 10 with 110 volts AC and a regulated DC voltage.

A portable DGPS receiver 20 is also connected to the PC 12. The DGPS radio receiver 20 receives DGPS data for use by
10 the PC to overcome the effects of Selective Availability (SA) as well as other imperfections in the time-coded signals broadcast by the NAVSTAR satellites. The use of DGPS provides a more accurate location solution than GPS alone. The DGPS radio receiver 20 may be any type of DGPS receiver
15 suitable for use with the present invention but is preferably the Smartbase model number 10, manufactured by Premier GPS Inc. Also note that the present invention would work without using DGPS, although the accuracy may be less. One alternative to the preferred embodiment is to use a receiver
20 that uses a combination of GPS and GLONASS signals to produce a more accurate radio navigation system.

A GPS antenna 22 is connected to the GPS receiver 14 to provide the GPS receiver 14 with GPS signals from the NAVSTAR satellites. The GPS antenna 22 acts as the collection point
25 for GPS signals received by the GPS receiver 14. The GPS antenna 22 is mounted to the host vehicle at a known location such that the location of the antenna 22 is always known relative to the GPS receiver 14 or some other reference point.
30   As shown in Figure 1, a number of sensors are also connected to the PC 12. Three rate gyros 24, three accelerometers 26, and a magnetic heading compass 28 are connected to the PC 12 to provide the system with various data. Preferably, the gyros 24, accelerometers 26 and the
35 magnetic heading compass 28 are assembled together in a single unit. A position change sensor 30, preferably comprised of a Doppler radar is also connected to the PC 12

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to provide the system with speed data. Although the
preferred embodiment uses three each of the gyros 24 and
accelerometers 26, more or less could be used. The choice of
using two or three accelerometers depends on such factors as
5   the level of accuracy desired, the application of the system,
and the sophistication of the Kalman filter, etc. The gyros
24 act as angular change sensors, so therefore, any device
with the same function could be substituted for the gyros 24.
The preferred gyros are the model ENV-05H-02 manufactured by
10 Murata Erie Co., Ltd. Similarly, the accelerometers 26 could
be substituted by an equivalent device such an inclinometer,
tilt sensors, etc. The preferred accelerometer is the model
02753-01 manufactured by Lucas Control System Products. The
magnetic heading compass could also be substituted by any
15 other heading sensor, for example, a fluxgate compass. The
preferred magnetic heading compass is the model C100
manufactured by KVH Industries, Inc. Also note that the
magnetic heading compass 28 is optional. Depending on the
sophistication of the Kalman filter and other factors, the
20 magnetic heading compass 28 may not be needed by the system.
The Doppler radar 30 functions as a position change sensor,
so therefore any equivalent device could be substituted for
the Doppler radar such as an odometer or any other device
used to derive the vehicle speed. The preferred Doppler
25 radar is the model Radar II manufactured by Dickey-John.

Figure 2 shows a functional block diagram of the
attitude/heading portion of the invention. The
navigation/guidance system 10 uses software which performs
the functions described and outlined in the figures. As
30 described below, the attitude integration algorithm 42 uses
the angular rates from the gyros 24, horizontal accelerations
from the horizontal accelerometers 26, and heading and
attitude error estimates from the other sensors to calculate
a value for the vehicle's attitude (pitch and roll) and
35 heading. The attitude and heading are primarily sensed by
the gyros 24. The various sensors are used together as shown
in the figures to obtain a more accurate value for attitude

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(pitch and roll) and heading. The data from the gyros 24 is
applied the gyro compensator function 40 which applies
constant values such as a scale factor, misalignment and
fixed bias to the data and also applies changing values such
5   as an estimated dynamic bias to the data. The data is then
provided to the attitude integration algorithm 42 to
calculate the attitude and heading. The horizontal
accelerometers 26 provide data to the accelerometer
compensation function 46 which applies constant values such
10 as scale factor, bias, and misalignments to the data. The
compensated data from the accelerometers 26 is then provided
to a direction cosine matrix (shown in Figure 2 as the body
to navigation frame transformation function 48) and a
platform leveling/damping function 50. The yaw attitude is
15 slaved to the magnetic heading reference supplied by the
magnetic heading compass 28. This, along with data from the
GPS position are used by a blending filter 44 to provide a
heading error estimate to the attitude integration algorithm
42. A pitch and roll error estimate is also provided to the
20 attitude integration algorithm 42. The pitch and roll error
estimate is derived from data from the Doppler radar 30, the
horizontal accelerometers 26, and the gyros 24.

        The attitude, heading and corresponding time are saved
in a data table for interpolation to the GPS data time. This
25 interpolated data is required to provide position corrections
to the GPS position fix (see discussion of Figure 3 below)
for use in the dead reckoning navigation function shown in
Figure 4 (discussed below).

        Figure 3 is a block diagram of the position correction
30 function. As described above, the GPS receiver 14 is
connected to the GPS antenna 22 to receive GPS data signals
from the NAVSTAR satellites. The GPS receiver 14 also
receives DGPS data from the DGPS radio receiver 20 to improve
the GPS accuracy. The position corrections lc, Lc are
35 calculated based on the latest position lr, Lr provided by
the GPS receiver 14, the saved/interpolated dead reckoned
position ls, Ls, and the GPS antenna moment arm (lever arm)

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corrections (discussed below) la, La based on the saved/interpolated attitude data corresponding to the GPS data time.

The system uses the attitude data from the navigation
5   system 10 for GPS antenna lever arm corrections. An antenna mounted on top of a vehicle such as a tractor or floater would be about 13 feet from the ground and will experience large attitude excursions as the vehicle swaths a field. As shown in Figure 3, the system takes this into account by
10   using the attitude data to make GPS position corrections based on the current attitude of the vehicle and the known position of the GPS antenna relative to the vehicle. As a result, as the vehicle travels over terraces, ruts, bumps, etc., the relatively large swings of the GPS antenna will not
15   effect the accuracy of the GPS position. Using similar techniques, the position calculated by the system can be transferred to any part of the vehicle, for example to the end of a sprayer boom.

Figure 4 shows a block diagram of the dead reckoning
20   navigation function. The velocity sensed by the Doppler velocity sensor 30 is transformed from mount to body axes, then transformed from body to local level axes using the attitude (pitch and roll) and heading data from the attitude integration algorithm 42 shown in Figure 2. After the body
25   to local level transform, the velocity is then transformed from local level to north referenced navigation axes. Finally, the data is provided to the position integration function 52 which is reset according to the available position correction values lc, Lc coming from the position
30   correction function shown in Figure 3.

Figure 5 shows a block diagram of the guidance function of the present invention. As shown in Figure 5, the position of the vehicle determined by the position integration (Figure 4) is supplied to a guidance algorithm 54 along with the
35   vehicle's heading and the desired path. The guidance algorithm 54 uses this data to determine the cross track error and the heading error. From the cross track and

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heading errors, the system creates guidance commands. The guidance commands are provided to an operator perceivable display 56 and/or an automatic steering mechanism 58 (see discussion below). The display 56 may take on any form. The

5   display 56 could be display unit 18 (discussed above), a light bar (discussed below), or any other type of operator perceivable indicator. The automatic steering mechanism 58 could also take on any form. For example, the steering mechanism could be a hydraulic steering mechanism.

10   The navigation/guidance system of the present invention operates as follows. Before the host vehicle moves, the navigation system will initialize itself. The attitude (pitch and roll) is initialized by the accelerometers 26. The heading is initialized by the magnetic heading compass

15 28. The heading initialization is the most important initialization step. If the vehicle is moving the magnetic heading compass 28 will not be used to initialize the heading. The system is initialized based on where the operator of the vehicle indicates the vehicle is located

20 and/or by GPS data. In other words, the operator can manually enter in the initial location and/or the system can use the GPS location.

        Once the host vehicle begins moving the system 10 uses the various sensors to sense the movement of the vehicle.

25 The attitude (pitch and roll) and heading of the host vehicle is sensed by the gyros 24. The speed of the vehicle is sensed by the Doppler radar 30. After sensing the attitude, heading, and speed, the system 10 calculates the velocity of the vehicle. The velocity of the vehicle is then integrated

30 to determine the position of the vehicle. The system then uses a process to correct for errors in the system (see Figure 3). The speed, heading and dead reckoning position errors are corrected by periodic GPS fixes. The attitude pitch and roll errors are corrected by sensing the

35 acceleration caused by the motion of the vehicle. This is done via the accelerometers 26 and the knowledge of the vehicle speed and rotation rate. The accelerometers 26 sense

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the specific force accelerations acting on the vehicle
including gravity, the acceleration of the vehicle, and
centrifugal force. The gravity force is a known value and
can be subtracted out. The remaining accelerations are then
5   integrated to get a velocity. Similarly, the velocity and
rotation rate of the vehicle are known and can be subtracted
out. The remaining values can be used to correct the
attitude errors.

A vehicle using the navigation system 10 to help control
10   a guidance system operates as follows and as described with
Figure 5 above. The primary information used by the guidance
system from the navigation system 10 is the position of the
host vehicle. As shown in Figure 5, the guidance system
receives a position signal from the navigation system 10 at a
15   rate of 10 Hz. The guidance system also receives a vehicle
heading signal from the navigation system 10 at a 10 Hz rate.
Of course, the position and heading data could be received at
any other suitable rate, but 10 Hz is the preferred rate.
The desired path of the vehicle is provided to the guidance
20   system from the processor memory, user input, or any other
source. The guidance system computes cross track and heading
error. Cross track error is the distance the vehicle is off
from the desired path. Heading error is defined as the
angular difference between the vehicle velocity and the
25   desired path. The goal of the guidance system is to drive
the cross track error to zero by guiding the vehicle along a
desired path. The guidance algorithm 54 described above
calculates the cross track error and the heading error to
create guidance commands. These guidance commands are the
30   steering signal used by the operator or by an automatic
steering mechanism to steer the vehicle along the desired
path.

A vehicle equipped with the navigation system 10 of the
present invention is capable of very accurately keeping track
35   of where the vehicle is and where it has already been. This
information can be used for any number of purposes or
applications. The navigation system provides accurate, real

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time data sufficient to allow a guidance system to navigate
along a curved path.

     With the navigation system 10 of the present invention
used on an agricultural vehicle such as a tractor or floater,
5   the vehicle would have many capabilities. An operator of the
vehicle could manually steer through a path in the field and
then use the system to guide the vehicle almost exactly
parallel to the path on the next swath (see Figure 7,
discussed below). This would maximize the efficiency of the
10 vehicle and make the operator's tasks easier and more
reliable. Similarly, an operator of the vehicle could
manually navigate the vehicle around the edge of a field and
command the vehicle to automatically cover the remainder of
the field within the outside path. Since the system would
15 have the previous paths in memory, the system would know what
portions of the field remain and would be able to cover the
remainder of the field. The operator could also manually
navigate around waterways and allow the system to
automatically navigate around the waterways when they are
20 encountered. The system could also be used to help control
the operation of machinery such as sprayers, disks, etc.
connected to the vehicles. For example, when a vehicle is
turning around at the end of a field and is traveling over
areas already sprayed, the sprayers could be automatically
25 turned off until they reach a portion of the field not
previously sprayed. Whatever the system is used for, the
navigation information obtained could be saved and stored for
subsequent operations in the same field. For example, once
the system knows the locations of borders, obstacles, etc. in
30 a field, that information can be used later to automatically
navigate around a field without "relearning" that
information. That would make the system even more efficient
after the initial operation in a particular field.

     Figure 6 shows a tractor 60 incorporating the present
35 invention. A GPS antenna 22 is mounted to the top of the
tractor 60. The Doppler sensor 30 is mounted on the front of

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the tractor 60. The remaining components of the system 10 are also mounted to the tractor 60.

Figure 7 shows an aerial view of a field being worked by the tractor 60. The tractor is shown pulling a sprayer 62
5   through the field. As shown in Figure 7, the tractor 60 first sprayed the end rows 64. Next, the tractor was guided along a first swath 66A which followed the shape of the edge of the field. Dashed line 68A shows the path of the tractor 60 during the first swath 66A. The swath 66A is shaded to
10   show that it was sprayed. At the end of the first swath 66A, the guidance system, knowing the location of the end rows 64 and knowing the location of the first swath 66A is able to cause the tractor 60 to turn around and follow the path 68B to start the second swath 66B. Figure 7 shows the tractor 60
15   as it is making a fourth swath 66D following the path 68D. Also note that the sprayer 62 can be automatically turned off at the end of each swath 66 as the sprayers pass over portions of the field already sprayed. As discussed above, the system 10 is capable of navigating in a curved or uneven
20   path.

An agricultural floater equipped with the present invention would have many capabilities not found in the prior art. First, the reliability of the operators hired to operate the floaters would be less important. The guidance
25   system on the floater would enable the floater to automatically move through the field, for example with an automatic hydraulic steering system. Alternatively, the guidance system could assist the operator in moving through the field via a light bar or other display device. As a
30   result, the entire field would be covered with the proper amount of chemicals giving the farmer higher yields and saving the chemical supplier money from less wasted chemicals. Second, the floaters could operate at night since the operator would not need to watch for the foam markers or
35   other external indictors required by prior art systems. As a result, the chemical applier could use and maintain fewer floaters to spray the same amount of land.

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Other applications of the present invention can be seen
as well. For example, when the navigation/guidance system is
applied to any other vehicle, many of the same advantages are
found. In addition, given a typical $90,000 tractor, $60,000
5   of that cost goes toward the creature comforts such as a cab,
air conditioning, etc. With a fully automatic guidance
system, the operator and hence the creature comforts are not
needed and $60,000 could be cut from the price of the
tractor. The navigation/guidance system could also be used
10   to quickly and efficiently survey land. With the system
installed on a vehicle, for example a 4-wheeler, a user could
simply drive over a given piece of land while the system
keeps a record of precisely where the vehicle has been and
the elevation at each point. This data could be transmitted
15   or downloaded to a computer to be interpreted and used.
Software such as CAD could then be used to create three
dimensional maps of the surveyed land. Lawn services could
use the navigation/guidance system with lawn sprayers or
mowers as described above. Excavating machinery such as
20   bulldozers could use the system to automatically excavate
land. The navigation system is also capable of use on boats
or ships. Vehicles traveling through water encounter similar
problems as do vehicles traveling on the ground. For
example, waves and strong winds as well as other forces can
25   dramatically manipulate the attitude of the ship causing
problems described above such as the GPS antenna lever arm
errors. The navigation system could also be used on boats to
survey the bottom of bodies of water. An additional sensor
such as sonar could be used to sense the depth of the water
30   at every location that the boat traveled over. This data
could be used to determine where silt build-up exists around
dams for example. The rail industry could use the
navigation/guidance system to keep track of and control
trains. The navigation system will continue to operate even
35   while the trains go trough tunnels or under foliage, etc.
The railroads could fit more trains on a given track if they
knew precisely where each train was. Also, the system is

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accurate enough to indicate which track a train is on, even
where two tracks run parallel in close proximity. Regardless
of how the present invention is used, the user will save
time, labor, cost, etc.

5   The preferred embodiment of the navigation system 10 of
the present invention may be configured as follows. A sensor
package is contained within a single enclosure. The sensor
package includes the rate gyros 24, the accelerometers 26 and
the magnetic heading compass 28. The sensor package could

10   act as a stand-alone inertial measurement unit with the
capability of connecting to a vehicle and any other sensors
desired. The Doppler radar position sensor 30 is attached to
the vehicle and preferably pointed downward toward the ground
at an angle of about 30°. A display head includes the

15   display unit 18, the processor 12, the GPS receiver 14, a
tactile device (e.g., a keypad or keyboard), the DGPS radio
receiver and the required power supplies. Two antennas (one
GPS and one DGPS) are attached to the vehicle and connected
to the appropriate receiver. Finally, a light bar is

20   installed on the vehicle in view of the operator and also
connected to the display head. The light bar is comprised of
a row of lights that indicate the magnitude and direction of
the cross track error to the operator. In response to the
light bar indication the operator could steer left or right

25   in order to continue on a desired path. Optionally, the
system 10 may provide guidance commands to an automatic
steering mechanism.

The preferred embodiment of the present invention has
been set forth in the drawings and specification, and

30   although specific terms are employed, these are used in a
generic or descriptive sense only and are not used for
purposes of limitation. Changes in the form and proportion
of parts as well as in the substitution of equivalents are
contemplated as circumstances may suggest or render expedient

35   without departing from the spirit and scope of the invention
as further defined in the following claims.

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What is claimed is:

1.   A method of navigating a non-airborne vehicle comprising
the steps of: providing a position change sensor; sensing
5   the speed of the vehicle using the position change sensor;
providing an angular change sensor; sensing the heading and
attitude of the vehicle using the angular change sensor;
providing an accelerometer; correcting the sensed attitude of
the vehicle using data from the accelerometer, position
10   change sensor and angular change sensor; determining the
position of the vehicle based on a known previous position
and the sensed speed, heading, and attitude of the vehicle;
providing a radio navigation system; determining an external
position reference using data from the radio navigation
15   system; and correcting any error in the determined position
of the vehicle using the determined external position
reference.

2.   The method of claim 1 further comprising the steps of:
20   providing a radio navigation antenna for use with the radio
navigation system, said antenna having a known location
relative to a reference point on the vehicle; determining the
position of the radio navigation antenna based on the
attitude of the vehicle and the known location of the antenna
25   relative to the reference point; and determining the external
position reference using data from the radio navigation
system and using the determined position of the radio
navigation antenna.

30   3.   A navigation system for a non-airborne vehicle
comprising: a position change sensor for sensing the speed
of the vehicle; a set of gyros for sensing the attitude and
heading of the vehicle; a set of accelerometers for sensing
the forces acting on the vehicle; a radio navigation system
35   for sensing an external reference position reference, said
radio navigation system including an antenna coupled to said
vehicle at a known location relative to the vehicle; and a

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SUBSTITUTE SHEET (RULE 26)

processor connected to each of said sensors and radio
navigation system, said processor performing the processing
steps of: correcting the sensed attitude of the vehicle
using the sensed forces acting on the vehicle; determining
5 the velocity of the vehicle using the sensed speed, heading
and attitude of the vehicle, determining a first position by
integrating the determined velocity, determining the position
of the antenna based on the attitude of the vehicle and the
known location of the antenna relative to the vehicle,
10 correcting the external reference position based on the
determined position of the antenna, and correcting the
determined first position using the corrected external
reference position.

15 4.   A method of navigating a land-based agricultural vehicle
through a field comprising the steps of: sensing the speed
of the vehicle; providing an inertial sensor system; sensing
the heading and attitude of the vehicle using the inertial
sensor system; determining the position of the vehicle based
20 on a known previous position and the sensed speed, heading,
and attitude of the vehicle; providing a radio navigation
system; determining an external position reference using data
from the radio navigation system; producing true position
data by correcting any error in the determined position of
25 the vehicle using the external position reference; and using
the true position data to accurately navigate through a
field.

5.   The method of claim 4 further comprising the steps of:
30 providing a radio navigation system antenna coupled to the
vehicle at a known location relative to the vehicle;
determining the position of the antenna based on the attitude
of the vehicle and the location of the antenna relative to
the vehicle; and refining the determined external position
35 reference based on the determined position of the antenna.

SUBSTITUTE SHEET (RULE 26)

6.   The method of claim 4 further comprising the steps of:
sensing the acceleration caused by the vehicle; using the
sensed acceleration caused by the vehicle to refine the
determined position of the vehicle.

5

7.   A method of compensating for a radio navigation system
antenna lever arm for a non-airborne vehicle comprising the
steps of: providing a radio navigation system antenna having
a known location relative to a reference point on the

10   vehicle; providing an inertial system for sensing the angular
changes and of the vehicle; determining the attitude of the
vehicle using data from the inertial system; and determining
the position of the radio navigation system antenna based on
the attitude of the vehicle and the known location of the

15   radio navigation system antenna relative to the reference
point.

8.   A navigation system for a tractor comprising: a
position change sensor for sensing the speed of the tractor;

20   a set of gyros for sensing the attitude and heading of the
tractor; a set of angular change sensors for sensing the
pitch and roll of the tractor; a radio navigation system for
sensing an external reference position reference, said radio
navigation system including an antenna coupled to said

25   tractor at a known location relative to the tractor; a
processor connected to each of said sensors and radio
navigation system, said processor performing the processing
steps of: correcting the sensed attitude of the tractor
using the sensed pitch and roll of the tractor; determining

30   the velocity of the tractor using the sensed speed, heading
and attitude of the tractor, determining a first position by
integrating the determined velocity, determining the position
of the antenna based on the attitude of the tractor and the
known location of the antenna relative to the tractor,

35   correcting the external reference position based on the
determined position of the antenna, and correcting the
determined first position using the corrected external

20

reference position; an output port connected to said
processor for providing data to a tractor guidance system.

9.   The navigation system of claim 8 further comprising a
5   user perceivable display connected to said processor for
displaying information.

10.   The navigation system of claim 8 wherein said tractor
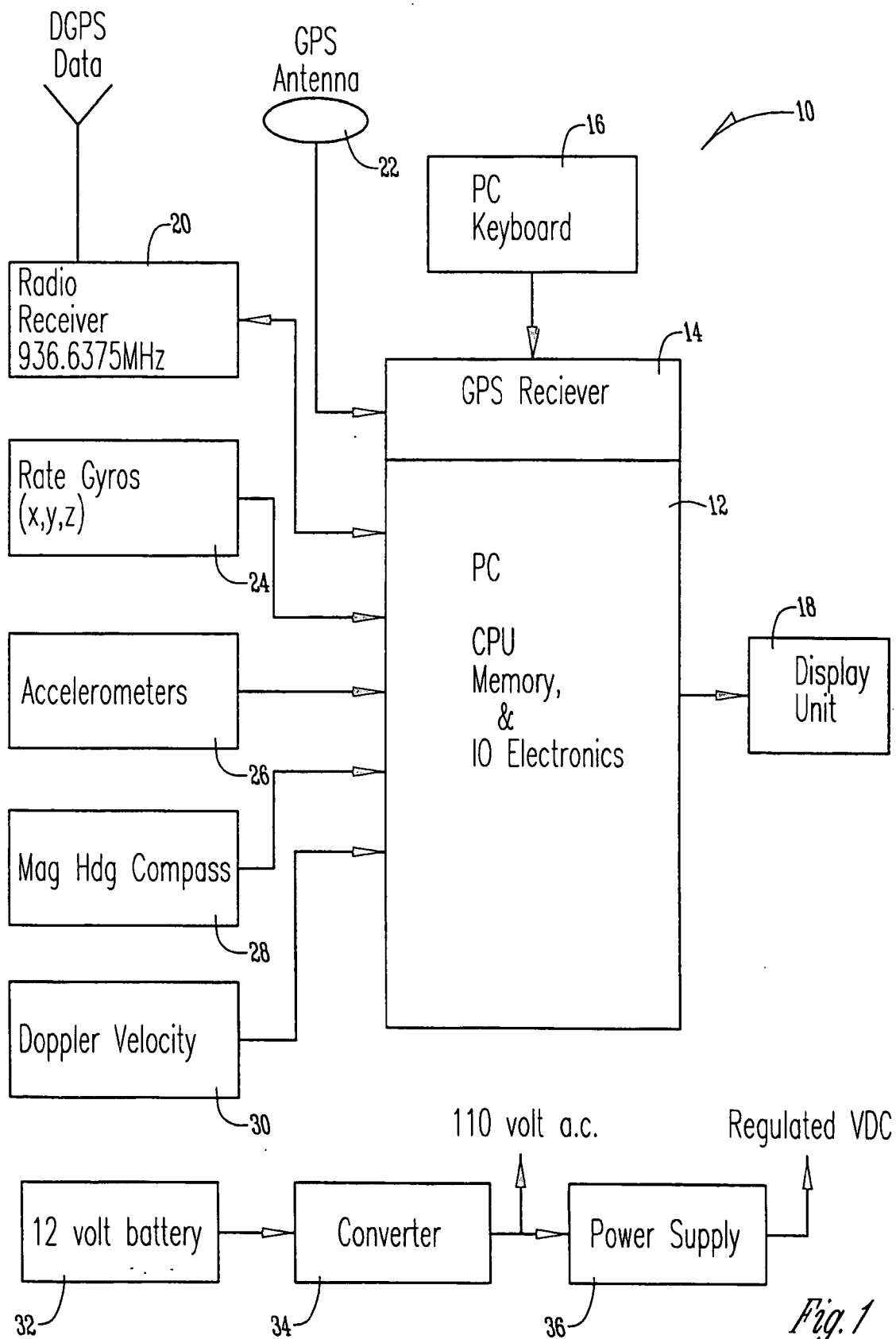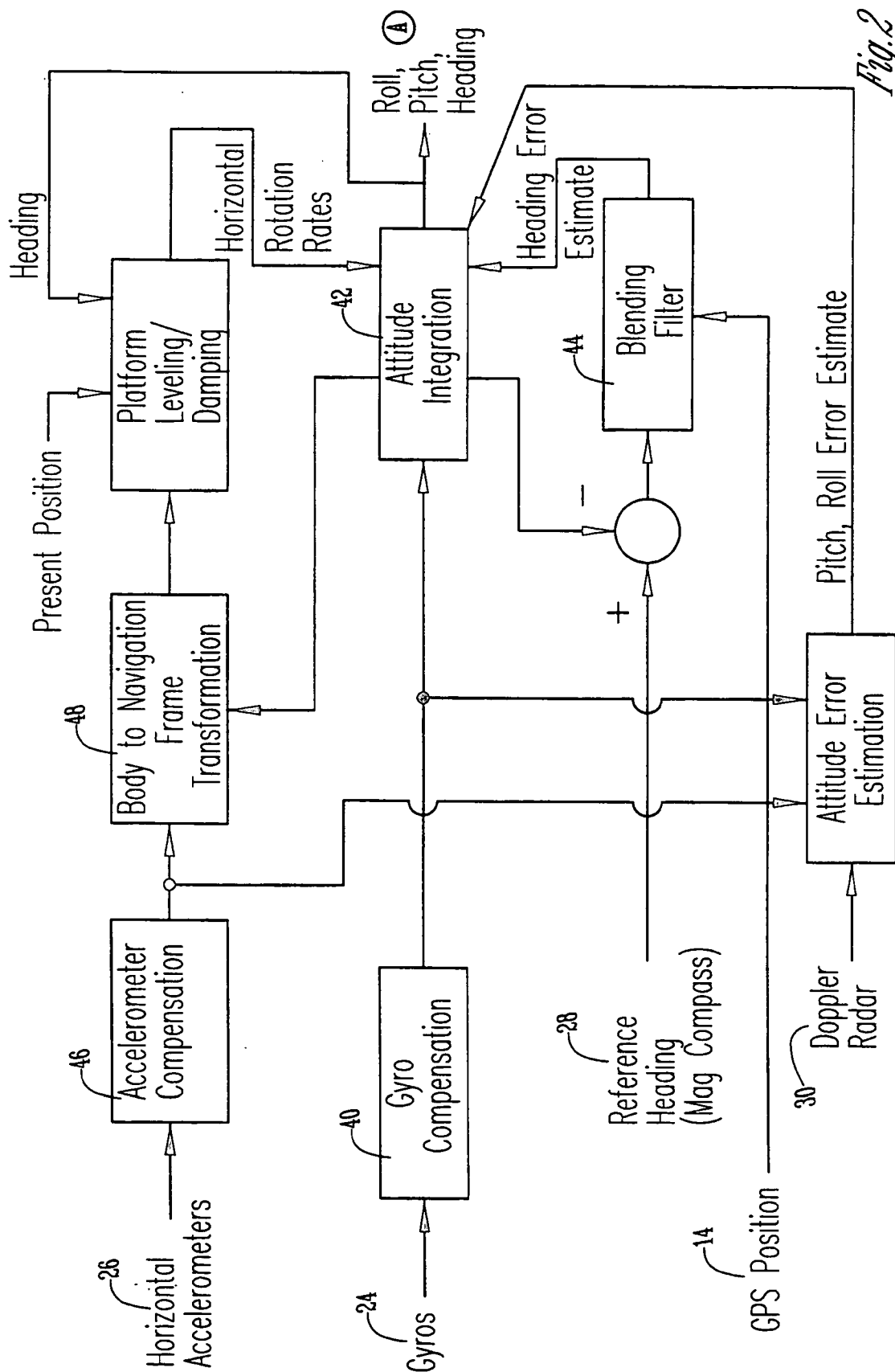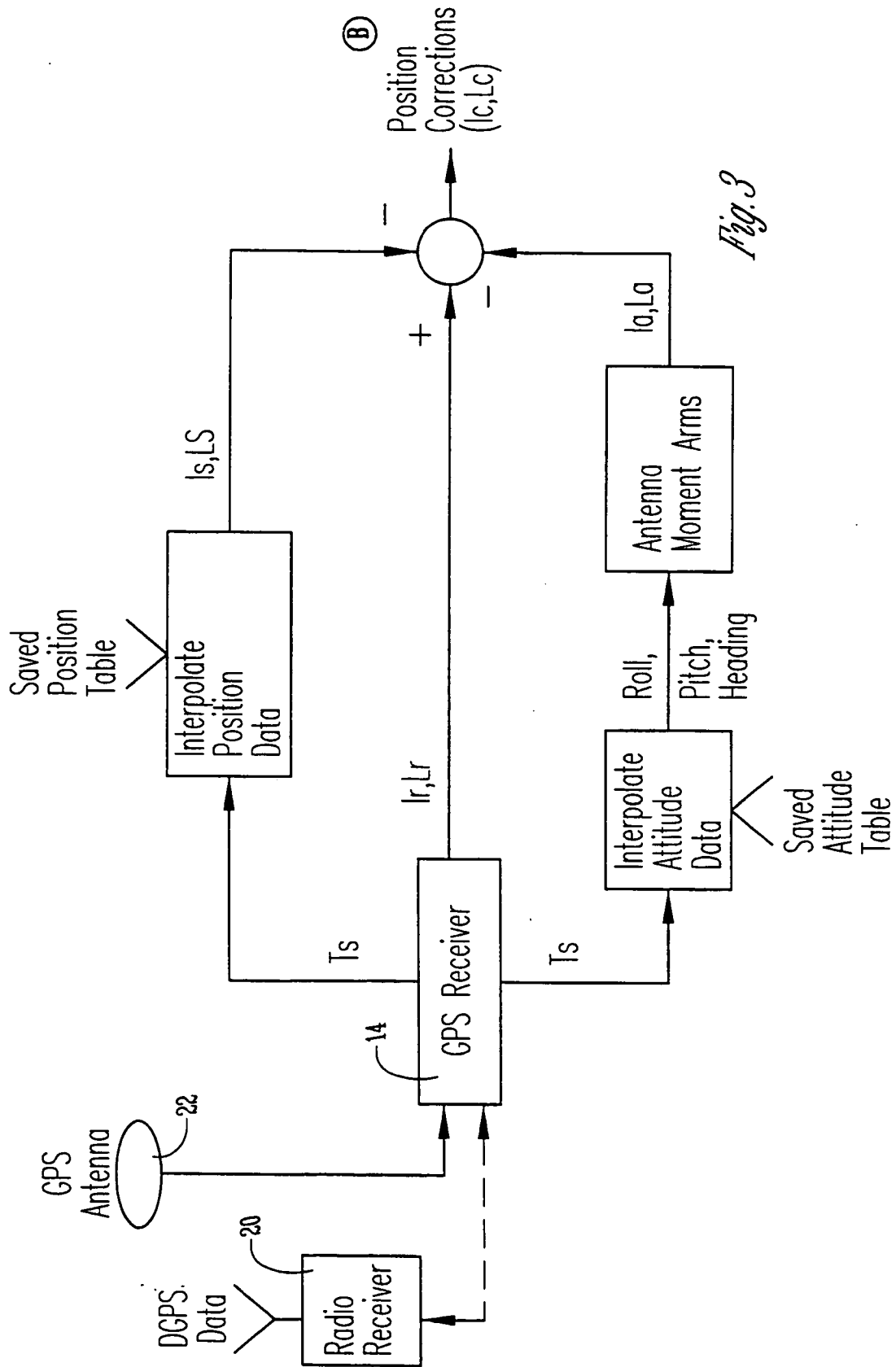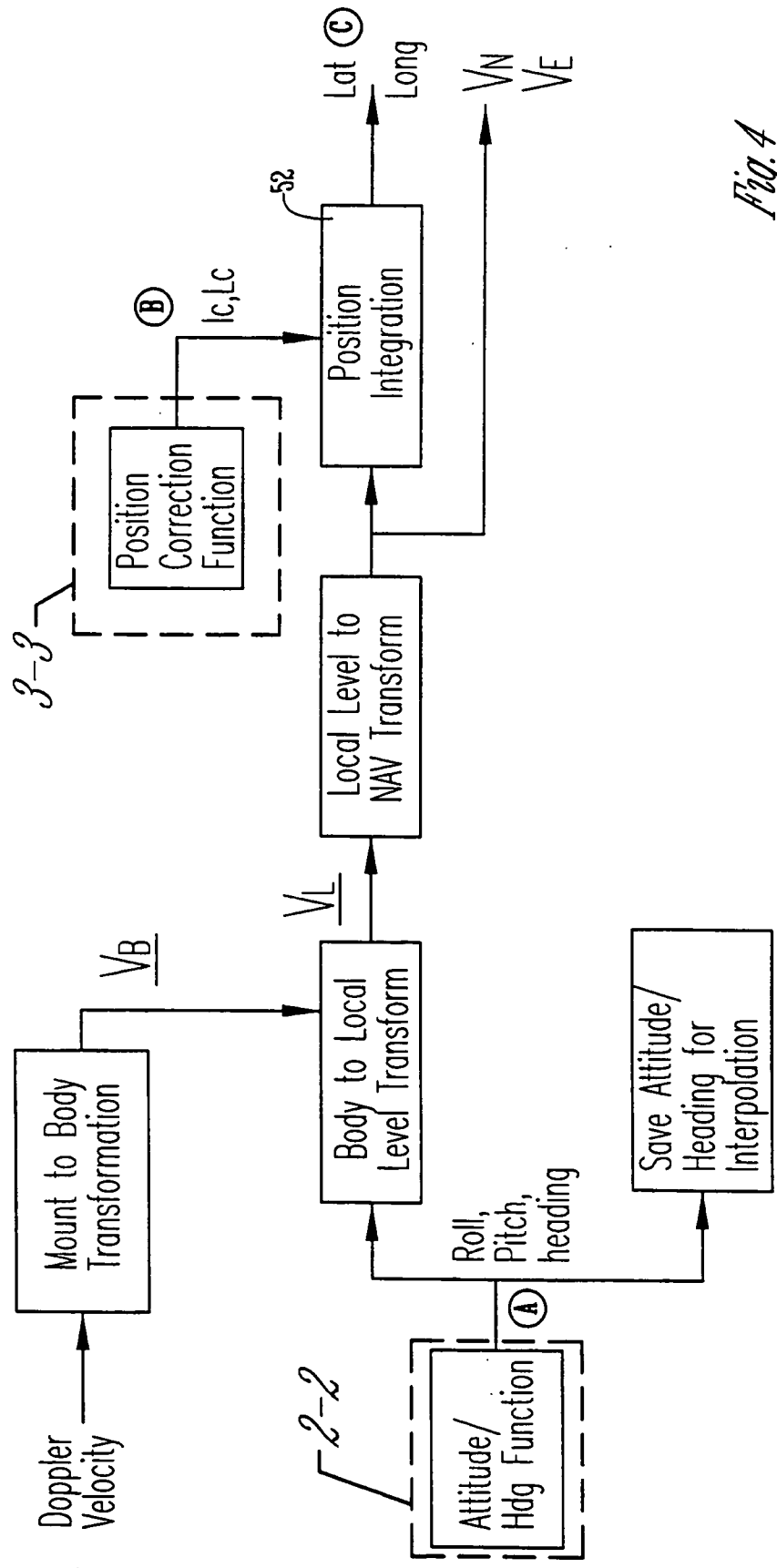guidance system is comprised of an automatic steering system.

21

DGPS
Data

GPS
Antenna

PC
Keyboard ——16

10

——22

Radio
Receiver
936.6375MHz ——20

GPS Reciever ——14

——12

Rate Gyros
(x,y,z)

PC

CPU
Memory,
&
IO Electronics

——24

Accelerometers

Display
Unit ——18

——26

Mag Hdg Compass

——28

Doppler Velocity

——30

110 volt a.c.   Regulated VDC

12 volt battery

Converter

Power Supply

32   34   36

Fig.1

Fig.2

Fig.3

Fig. 4

Fig.5
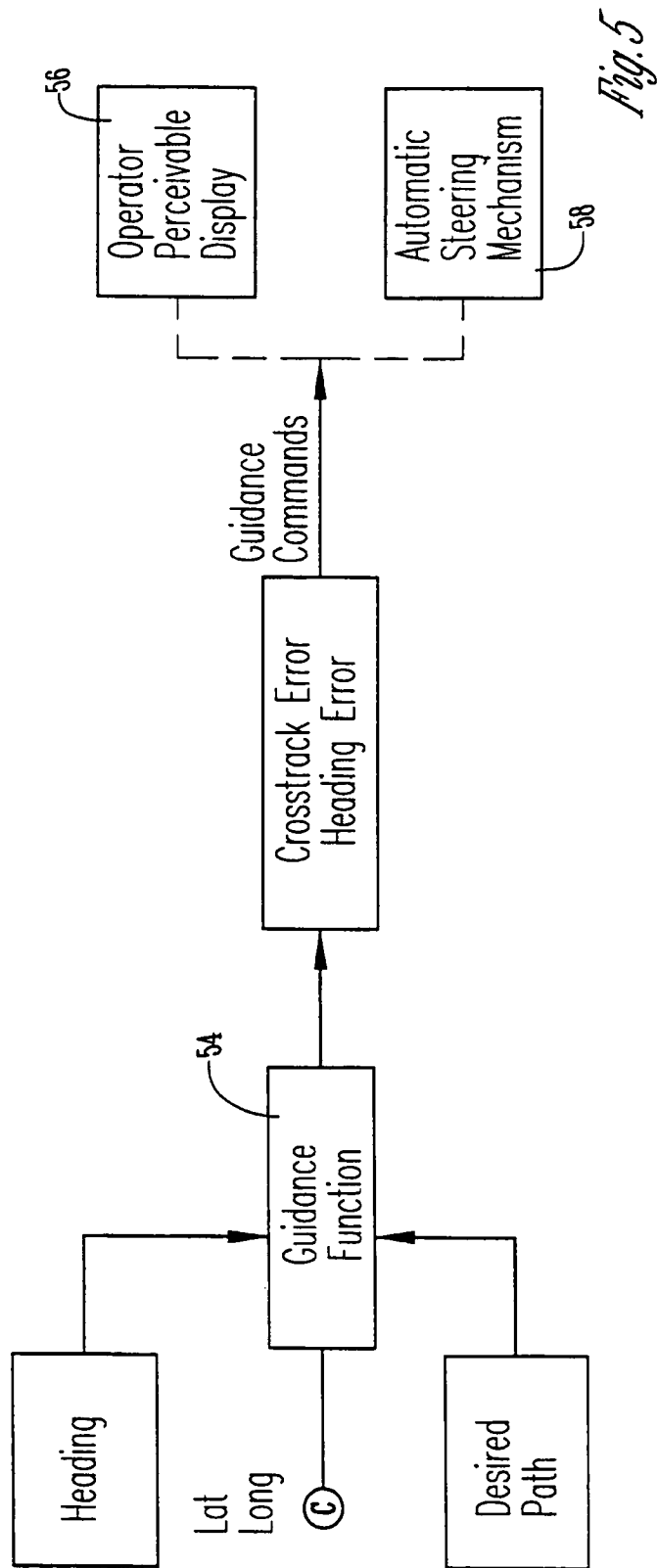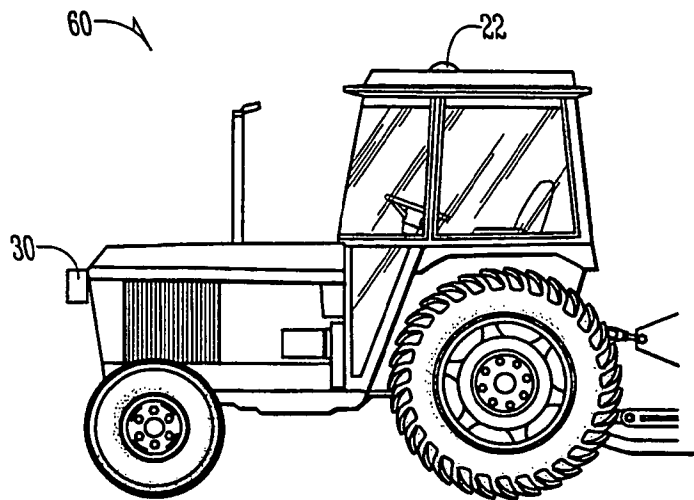
Fig.6

Fig.7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   G01S5/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   G01S   G01C   G05D   A01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 91 09375 A (CATERPILLAR INC) 27 June 1991 see page 41, line 5 - page 42, line 28; figure 10 ---	1-4,7,8, 10
X	WO 95 18432 A (CONCORD INC) 6 July 1995 see abstract; claims 1-4; figure 1 ---	1
Y	P. DAUM ET AL: "AIDED INERTIAL LAND NAVIGATION SYSTEM (ILANA) WITH A MINIMUM SET OF INERTIAL SENSORS" POSITION LOCATION AND NAVIGATION SYMPOSIUM (PLANS), LAS VEGAS, APR. 11 - 15, 1994, no. -, 11 April 1994, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 284-291, XP000489353 see page 284, right-hand column ---	1,3,4,7, 8

-/--

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 October 1997	04.11.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Breusing, J

Form PCT/ISA/210 (second sheet) (July 1992)

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 716 315 A (SUMITOMO ELECTRIC INDUSTRIES) 12 June 1996 see column 3, line 33 - column 4, line 10; figure 1 see column 4, line 45 - column 5, line 36 ---	1,3,4,7, 8
A	PATENT ABSTRACTS OF JAPAN vol. 016, no. 460 (P-1427), 24 September 1992 & JP 04 164277 A (HONDA MOTOR CO LTD), 9 June 1992, see abstract ---	4
A	US 5 517 419 A (LANCKTON ARNOLD H ET AL) 14 May 1996 see column 5, line 24 - column 6, line 67 ---	1,2,5
A	DE 196 04 812 C (HOELZL HANS) 12 December 1996 see the whole document ---	1,4
A	EP 0 736 441 A (HONEYWELL AG) 9 October 1996 see column 2, line 7 - column 3, line 19; figure 2 ---	1
A	DE 195 04 475 A (FUJI JUKOGYO) 17 August 1995 see abstract; claim 1; figure 1 ---	1,4
A	US 5 075 693 A (MCMILLAN JOSEPH C ET AL) 24 December 1991 see column 3, line 23 - column 4, line 48 see column 10, line 8 - line 32; figure 2 -----	

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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		EP	0679973 A	02-11-95
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		EP	0679974 A	02-11-95
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US 5075693 A	24-12-91	CA	1321418 A	17-08-93

JP07244150 A
ATTITUDE MEASURING APPARATUS OF HEAVY MACHINE
FUJITA CORP
Inventor(s):KIKUTA KATSUYUKI ;OKANO MIKIO
Application No. 06055252 JP06055252 JP, Filed 19940228,A1
Published 19950919

Abstract: PURPOSE: To measure the inclination, the direction and the position of a heavy machine simply and with high accuracy.

CONSTITUTION: GPS antennas 11 to 14 are installed in four corner parts on a heavy machine, and GPS radio waves from a GPS satellite are received by respective receivers 15 to 18 through the individual GPS antennas 11 to 14. Thereby, individual pieces of coordinate data on the WGS-84 system (a worlwide positioning system) in the four corner parts on the heavy machine are acquired, the individual pieces of coordinate data are taken into a processor module 19, they are converted into a three-dimensional orthogonal coordinate system in conformity with the Japanese positioning system, the position, the inclination and the direction of the heavy machine are then computed in real time on the basis of individual three-dimensional coordinates, and the attitude of the heavy machine is measured.

Int'l Class: G01S00514;   G01C00900 G01C01500

Patents Citing this One: No US, EP, or WO patents/search reports have cited this patent.
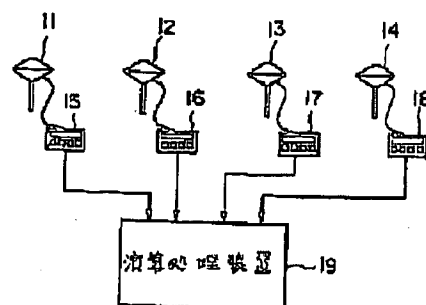
(51)Int.Cl.⁶		識別記号	庁内整理番号	FI	技術表示箇所
G01S	5/14		4240－5J		
G01C	9/00	Z			
	15/00	A			

審査請求　未請求　請求項の数3　FD　（全 4 頁）
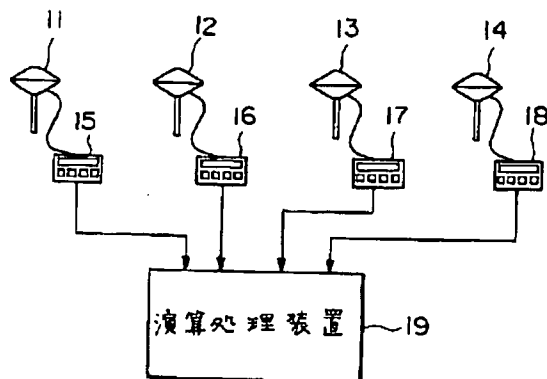
(54)【発明の名称】　重機の姿勢計測装置

(57)【要約】
【目的】　重機の傾き、向き、位置を簡便に、かつ高精度に計測することを目的とする。
【構成】　重機10上の四隅部分にGPSアンテナ11～14を設置し、この各GPSアンテナ11～14を通してそれぞれの受信機15～18でGPS衛星からのGPS電波を受信することにより、重機10の四隅部分におけるWGS－84系（世界測地系）の各座標データを取得し、この各座標データを演算処理装置19に取り込んで日本測地系に準拠する三次元直行座標系に変換した後、この各三次元座標から重機10の位置、傾きおよび向きをリアルタイムに算出して重機の姿勢を計測する構成にした。

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【特許請求の範囲】

【請求項1】　重機上の任意複数の位置にそれぞれ設置された複数のGPSアンテナと、

前記各GPSアンテナに到来するGPS衛星からの電波を受信して世界測地系の座標データを取得する受信機と、

前記各GPSアンテナ位置に対応する前記世界測地系の座標データを三次元直交座標データに変換する座標変換手段と、

前記座標変換手段で変換された各三次元直交座標データに基づいて前記重機の位置、傾き、向きを算出する演算処理手段と、

を備えてなる重機の姿勢計測装置。

【請求項2】　前記受信機は、前記各GPSアンテナ毎に設けられる請求項1記載の重機の姿勢計測装置。

【請求項3】　前記各GPSアンテナの受信機を共通にし、この共通の受信機と前記各GPSアンテナ間に該GPSアンテナの1つを選択的に共通の受信機に切り替え接続する選択回路を設けてなる請求項1記載の重機の姿勢計測装置。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、GPS（全地球測位システム）を利用した重機の姿勢計測装置に関する。

【0002】

【従来の技術】従来、広大な土木建設現場などにおいて、独自の土木作業を行うブルトーザ、ショベル系掘削機、トレンチャ、スクレーパ、クローラダンプ等の建設用重機の姿勢、つまり重機のピッチング方向・ローリング方向の傾きや重機の向きを計測する手段には、ジャイロ、磁気方位センサ及びトータルステーションが使用される。このうち、ジャイロは、その角加速度の数値積分から重機の方位又は傾きを求めるものであり、磁気方位センサは重機の方位（向き）を検出し、また、トータルステーションは重機の三次元位置を検出するものである。

【0003】

【発明が解決しようとする課題】しかしながら、上述のような従来の姿勢計測装置では、ジャイロによる方位または傾きは角加速度を逐次積分することで得られるため、測定誤差が累積し、方位または傾き精度が低下する問題がある。また、磁気方位センサでは、方位しか求めることができず、さらに、トータルステーションによる測量では、ある1点での三次元座標しか求めることができない。従って、上記各検出データを用いて重機の姿勢を制御する場合は、各検出データを統合処理しなければならず、しかも重機の姿勢計測精度も悪いほか、ジャイロ、磁気方位センサ等の重機への設置も面倒になるという問題があった。

【0004】本発明は、前記事情に鑑みてなされたもの

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であり、その目的とするところは、重機の傾き、向き、位置を簡便に、かつ高精度に計測できる重機の姿勢計測装置を提供することにある。

【0005】

【課題を解決するための手段】前記目的を達成するために請求項1の発明は、重機上の任意複数の位置にそれぞれ設置された複数のGPSアンテナと、前記各GPSアンテナに到来するGPS衛星からの電波を受信して世界測地系の座標データを取得する受信機と、前記各GPSアンテナ位置に対応する前記世界測地系の座標データを三次元直交座標データに変換する座標変換手段と、前記座標変換手段で変換された各三次元直交座標データに基づいて前記重機の位置、傾き、向きを算出する演算処理手段とを備える構成にした。

【0006】請求項2の発明は、前記受信機を前記各GPSアンテナ毎に設けたものである。請求項3の発明は、前記各GPSアンテナの受信機を共通にし、この共通の受信機と前記各GPSアンテナ間に該GPSアンテナの1つを選択的に共通の受信機に切り替え接続する選択回路を設けてなるものである。

【0007】

【実施例】以下、本発明の実施例を図面に基づいて説明する。図1は、本発明を適用した重機および該重機へのGPSアンテナの取付状況を示す説明図、図2は本発明の重機姿勢計測システムの一例を示す概略構成図である。図1において、10は宅地造成、ダム建設などの土木建設現場で独自の作業を自律的に行うクローラダンプ、ブルトーザ、ショベル系掘削機、トレンチャ、スクレーパ等の重機であり、この重機10上には、該重機10の姿勢計測に必要な座標を得るための複数の位置、例えば重機10の前後左右の四隅部分に位置してGPSアンテナ11〜14がそれぞれ設置され、これらのGPSアンテナ11〜14はそれぞれの支持部材11a〜14aによって重機10から同一の高さに支持されている。また、各GPSアンテナ11〜14は、図略の1つ以上のGPS衛星から到来するGPS電波を受信する。

【0008】図2において、各GPSアンテナ11〜14には、それぞれのアンテナ11〜14で捕捉したGPS電波を受信する受信機15〜18がそれぞれ接続されており、この各受信機15〜18で受信したGPS電波は、マイクロコンピュータからなる演算処理装置19に取り込まれる構成になっている。前記演算処理装置19は、重機10の姿勢に応じて各GPSアンテナ11〜14から得られる三次元座標を基に重機10の傾き、方位（向き）、位置をリアルタイムに演算する。

【0009】次に、上記のように構成された本実施例の重機姿勢計測動作について、図3のフローチャートを参照して説明する。まず、各GPSアンテナ11〜14および受信機15〜18を動作モードにし、GPS衛星からの電波を各GPSアンテナ11〜14を通してそれぞ

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れの受信機15〜18で受信することにより、重機10の四隅部分におけるWGS−84系（世界測地系）の各座標データを取得し、この各座標データは、それぞれの受信機15〜18に内蔵されている記憶部に一時記憶される（ステップS1）。

【0010】各受信機15〜18に一時記憶されたWGS−84系の座標データは演算処理装置19に順番に取り込まれ（ステップS2）、この各WGS−84系の座標データを日本測地系に準拠する三次元直行座標系に変換し（ステップS3）、次のステップS4において、重機10の四隅部分の三次元座標を算出する。次のステップS5では、上記四隅部分の各三次元座標データに基づいて、土木建設現場における重機10の位置、重機10のローリングおよびピッチング方向の傾き、および重機10の向きをそれぞれ算出する。そして、上記算出された位置、傾き、向きの各データに基づいて、重機10が安全に、かつ効率よく作業ができるように、重機10の姿勢を制御する（ステップS6）。

【0011】上記のように本実施例においては、重機10上の四隅部分にGPSアンテナ11〜14を設置し、この各GPSアンテナ11〜14を通してそれぞれの受信機15〜18でGPS衛星からのGPS電波を受信することにより、重機10の四隅部分におけるWGS−84系（世界測地系）の各座標データを取得し、この各座標データを演算処理装置19に取り込んで日本測地系に準拠する三次元直行座標系に変換した後、この各三次元座標から重機10の位置、傾きおよび向きをリアルタイムに算出して重機の姿勢を計測する構成にしたので、従来のような測定誤差の累積がなく、重機10の位置、傾き、向きを高精度（±20mm以内）に測定することができる。また、本実施例にける重機10の姿勢計測機器はGPSアンテナであるため、比較的激しい作業を行う重機であっても、その姿勢計測に支障を来すおそれがないほか、GPSアンテナの取付け、取外しおよびGPSアンテナ数の増減も簡単に行うことができる。

【0012】図4は、本発明方法の他の実施例を示す要部の構成図である。この他の実施例においては、図4に示すように、GPSアンテナ11〜14の受信機20を1台で構成し、この受信機20と各GPSアンテナ11〜14間には、GPSアンテナ11〜14の1つを選択的に受信機20に切り替え接続する選択回路21を設ける。そして、この選択回路21は演算処理装置19からの選択指令信号によって制御されるとともに、選択回路21により選択されたGPSアンテナの受信電波は受信機20で受信され、演算処理装置19に送出される。なお、演算処理装置19での処理は、図2に示す場合と同様である。

【0013】上述のような他の実施例においては、受信機が1台で済み、重機の姿勢計測システムを低コスト化

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できる。

【0014】なお、本発明は、上記実施例に記載された構成のものに限らず、請求項に記載した範囲を逸脱しない限り、種々の変形が可能である。例えば、上記実施例では、GPSアンテナ11〜14を重機10の前後の四隅部分に設置した場合について説明したが、GPSアンテナの設置位置は、重機の姿勢計測に必要な座標が得られるものであれば、いずれの場合であってもよい。また、GPSアンテナの数も上記実施例に示す4個のもに限定されない。

【0015】

【発明の効果】以上説明したように本発明によれば、重機上の任意複数の位置にそれぞれ設置された複数のGPSアンテナと、前記各GPSアンテナに到来するGPS衛星からの電波を受信して世界測地系の座標データを取得する受信機と、前記各GPSアンテナ位置に対応する前記世界測地系の座標データを三次元直交座標データに変換する座標変換手段と、前記座標変換手段で変換された各三次元直交座標データに基づいて前記重機の位置、傾き、向きを算出する演算処理手段とを備える構成にしたので、測定誤差の累積がなく、重機の位置、傾き、向きを高精度に測定することができる。しかも、本発明における重機の姿勢計測機器はGPSアンテナであるため、比較的激しい作業を行う重機であっても、その姿勢計測に支障を来すおそれがなく、GPSアンテナの取付け、取外しおよびGPSアンテナ数の増減も簡単に行うことができるという効果を有する。

【0016】また、本発明によれば、前記各GPSアンテナの受信機を共通にし、この共通の受信機と前記各GPSアンテナ間に該GPSアンテナの1つを選択的に共通の受信機に切り替え接続する選択回路を設けることにより、GPSアンテナの受信機を共用化でき、重機の姿勢計測システムを低コスト化できる。

【図面の簡単な説明】

【図1】本発明を適用した重機および該重機へのGPSアンテナの取付状況を示す説明図である。
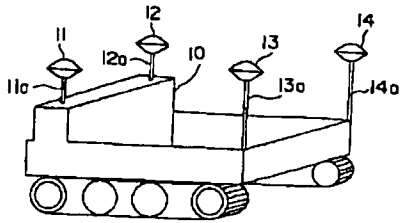
【図2】本発明の重機姿勢計測システムの一例を示す概略構成図である。

【図3】本実施例における重機姿勢計測の処理手順を示すフローチャートである。

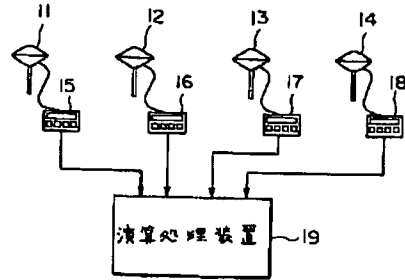【図4】本発明における重機姿勢計測システムの他の実施例を示す概略構成図である。

【符号の説明】

10　重機
11〜14　GPSアンテナ
15〜18　受信機
19　演算処理装置（座標変換手段）
20　共通の受信機
21　選択回路

【図1】

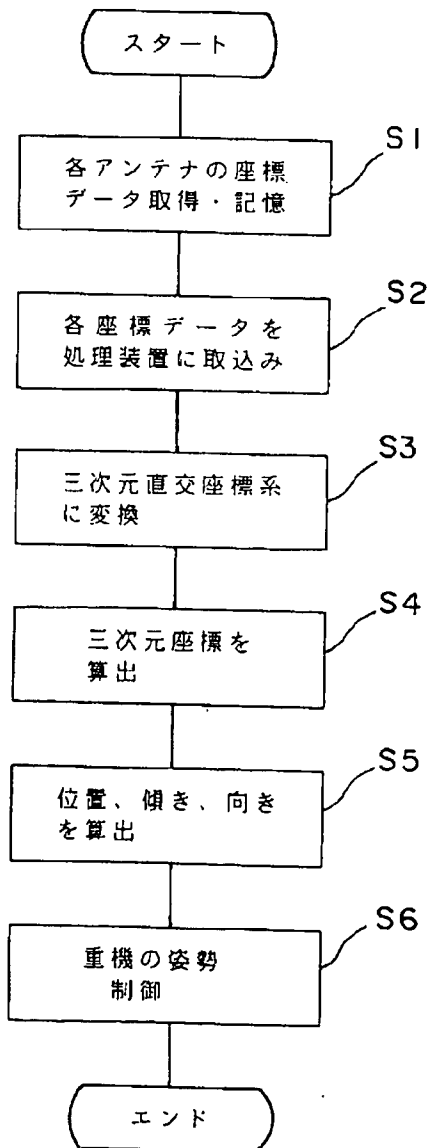【図2】

演算処理装置 ～19

【図3】

スタート

各アンテナの座標
データ取得・記憶　S1

各座標データを
処理装置に取込み　S2

三次元直交座標系
に変換　S3

三次元座標を
算出　S4

位置、傾き、向き
を算出　S5

重機の姿勢
制御　S6

エンド

【図4】

選択回路 ～21

受信機 ～20

演算処理装置 ～19